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Expanding sustainability learning in engineering education through emotional scaffolding

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ABSTRACT

Sustainability transformations involve wicked issues characterised by an absence of definite problem framings or solutions. Engineers play a crucial role in addressing such situations. However, engineers often lack the emotional capabilities to navigate open-ended and complex issues adequately. In this paper, we focus on the emotional challenges in engineering students' learning on wicked sustainability issues. We explore how *emotional scaffolding* can support engineering students in co-creating *new* ways of handling wickedness via expansive learning. Using a combination of narrative description and systematic mapping of emotional interactions, we analysed video data from student group work on wicked sustainability issues. We identified seven types of educational challenges that triggered expression of a wide range of emotions, and observed diversity in how enacted emotions hindered or enabled learning. We concluded that emotional scaffolding must be viewed as a system, and educators should focus on creating favourable emotional learning environments rather than attempting to micromanage students' emotions through generic interventions. To support in navigating the complexities of emotional scaffolding for sustainability learning, we propose a classification of scaffolding intents building on leverage point thinking. It ranges from shallow adjustments to learning environments to deeper transformations of the emotional logic underpinning teaching and learning.

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Emotional scaffolding; expansive learning; engineering education; sustainability transformations; emotion

1. Introduction

Contemporary sustainability challenges and transformations necessitate new ways of knowing, doing, being and relating in this world (Macintyre et al. 2018; Scoones et al. 2020; Wals 2009). Transformations to sustainability are deliberate and purposeful processes of change that operate on a level of societal systems and structures. Transformations are characterised by an open-ended complexity and uncertainty, giving rise to ambiguity and paradox in what can be framed as essentially wicked issues (Checkland 2010; Lönngren and van Poeck 2021; Rittel and Webber 1973). Here, various actors hold contrasting understandings, perspectives, and values on e.g. what constitutes a certain problem, where it comes from, why, and how to best move forward.

Engineers play a critical role in sustainability transformations and increasingly confront wicked issues where e.g. no definite problem framings or solutions exist. However, many engineering students

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do not get a chance to develop the capabilities they would need to handle such issues adequately, especially regarding the emotional challenges involved in navigating open-endedness, relational complexities, deliberation and recurring problem framing (Lönngren 2017; Mathebula 2018; Van Den Berg 2023). The emotional aspects associated with these processes hold significant potential in influencing how problematic situations are understood, engaged with, experienced and learnt from.

Emotions can be experienced as negatively and positively valenced, and they can both support and hinder learning (Ahmed 2014; Quinlan 2016a), depending on a wide range of personal, contextual, and educational factors (Pekrun and Linnenbrink-Garcia 2014). Despite their importance for teaching and learning processes, emotions (beyond discussions on how to develop engineering students' emotional intelligence) have so far been largely overlooked and under-researched in engineering education (Lönngren et al. 2024). In addition to missed opportunities for improving teaching and learning, a neglect of emotions and sole focus on analytic problem-solving in engineering education may further increase the tendency to privilege technicist problem solving, which tends to worsen rather than ameliorate wickedness (Hagvall-Svensson 2021; Leach, Scoones, and Stirling 2010; McCrory et al. 2021; Ross and Mitchell 2018). Opening for and exploring alternative and possibly more transformational pathways, on the other hand, provides an opportunity for deeper change – processes which to greater extents surface and involve emotions (Horcea-Milcu et al. 2019; Wamsler 2020; Woiwode et al. 2021).

Partly due to their importance for dealing with wickedness, emotions have been theorised to be especially apparent and influential in learning about sustainability issues (Lönngren, Adawi, and Holmén 2021; Ojala et al. 2021). For example, learning about and dealing with climate change tends to be accompanied by emotions such as anxiety, worry and grief (Ojala et al. 2021). Emotions also play an important role in mobilising hope, resistances and action for change (hooks 2003; Zembylas 2016). Moreover, when facing uncertainty or acting on the edge of what one is capable with or comfortable doing, emotions such as feeling overwhelmed, frustrated, insecure or confused may be present, but also emotions related to motivation, curiosity and excitement (Grund, Singer-Brodowski, and Büssing 2024; Holmén, Adawi, and Holmberg 2021).

Learning to deal with wicked sustainability issues while working for system transformations has been described as transformative social learning (Macintyre et al. 2018; Rodríguez Aboytes and Barth 2020; Winter et al. 2015). Transformative learning at large can be approached as a metatheory that encompasses many ways of understanding learning that go beyond conformative or acquisition-based models (Hoggan 2016). In transformative *social* learning, students may be involved as active co-constructors of their curriculum and learning processes rather than passive recipients of knowledge or information (Tilbury 2016). Expansive learning is a type of transformative social learning that has been positioned as particularly relevant for dealing with wicked issues (Engeström 2016; Larsson and Holmberg 2018; Lotz-Sisitka et al. 2015). Expansive learning centres around the navigation and resolution of issues with contradictory components or dilemma situations that at first may seem paradoxical. Expansion happens through transformative agency formation that gives shape to new concepts and objects, as learners confront and seek to overcome problematic situations by either experimenting with and creating or introducing novel concepts (Engeström and Sannino 2010).

In line with the sociocultural foundations of transformative and expansive learning theories, scaffolding has typically been considered a key mechanism in supporting such learning (Budwig 2015). In particular, emotional scaffolding (Lönngren, Adawi, and Berge 2021), specifically focusing on helping students overcome emotional challenges, has been found to be crucial to enhance learning about, for and in wicked sustainability challenges (Lönngren and van Poeck 2021). Recent research suggests viewing scaffolding as a systemic and distributed property of a learning situation or process, rather than as linear and teacher-led interventions (Puntambekar 2022). Yet, little is known about what emotional scaffolds and scaffolding systems can look like in practice and how they can be used to support transformative or expansive learning.

In this paper, we focus on emotional challenges and opportunities in expansive learning processes and the role of emotional scaffolding in such learning. We report on an empirical study

that aimed to develop strategies for how teachers and students can scaffold emotional experiences, expressions, and/or relationships to enhance learning. Drawing on sociocultural (Lave 1991; Lave and Wenger 1991) and expansive learning theory (Engeström 2016; Engeström and Sannino 2010; Lotz-Sisitka et al. 2015), combined with social interaction theories of emotion (Lönngren and Berge 2024; van Kleef 2016), we analyse how engineering students express, handle, and relate to emotions and emotion-objects when working with wicked sustainability challenges in small-group projects. We then critically discuss possibilities of emotional scaffolding to enhance expansivity in the associated learning processes.

We ask the following research questions:

1. What interactions can be observed between objects of enacted emotion, emotions, and possibilities for expansive learning in students' group work with wicked sustainability challenges?
2. How can different aspects of emotional scaffolding systems interact to create conditions for expansive learning?

2. Theory and background

2.1. Emotions in engineering and sustainability education

There is today a large body of research demonstrating the important roles emotions play in all teaching and learning. For example, emotions have been found to influence students' motivation to engage and learn and their approaches to learning. Emotions also influence whether learners are willing to face risks of failing as they engage with new and complex tasks, how they work in groups, and their (professional) identity and sense of belonging (e.g. Huff et al. 2021; Pekrun 2006; Pekrun and Linnenbrink-Garcia 2012; Postareff et al. 2017; Quinlan 2016b; Simpson and Maltese 2017; Tormey 2021; Volet, Seghezzi, and Ritchie 2019). Similarly, educators may employ different pedagogical approaches depending on how they feel about those approaches, and they may experience emotional stress when they experience lack of time, resources or confidence (e.g. Kordts-Freudinger 2017; Stupnisky, Hall, and Pekrun 2019; Trigwell 2012; Tunguz 2016). Clearly, emotions are present in all education, and they can have profound impact on individual and collective teaching and learning. So, what are emotions and why should we care about them in sustainability and engineering education?

Emotion is typically conceptualised as a multi-componential construct, combining the following elements: (1) motor expressions, such as gestures and facial expressions, (2) neurophysiological reactions, such as sweating or changing hormone levels, (3) subjective bodily experiences, such as feeling tightness over the chest, (4) motivation, for example wanting to achieve a goal or avoid an experience, and (5) cognition, such as cognitively evaluating an experience relative to one's values or conceptualising an experience as a certain emotion (Shuman and Scherer 2014). Theoretically, emotions can be framed in many ways. Two overarching approaches are cognitive appraisal theories and social interaction theories of emotions.

Cognitive appraisal theories explore emotions as individual phenomena. Emotions are conceptualised as appraisals of *objects of emotions*, artefacts or processes an individual experiences. Individuals evaluate whether an object of emotion is aligned with their own values and interests (triggering positive emotions) or in conflict (triggering negative emotions). The appraisal-valence circumplex model maps emotions in a circle along the axes of valence and arousal. Valence refers to the pleasant-unpleasant spectra of emotions (positive–negative), whereas arousal refers to its intensity (high activation-low activation). The model is visualised as a circle, where emotions that have an opposite relationship are placed opposing one another (180 degrees), whereas those with no correlation are placed 90 degrees apart (Barrett and Russell 1998). See also Figure 6 in the Result section of this particular paper for an example.

From these theories, we particularly draw on Pekrun et al.'s framework of *academic emotions* (e.g. Pekrun et al. 2007; Pekrun and Linnenbrink-Garcia 2012). Academic emotions are conceptualised as cognitive appraisal of objects of emotion that are common in educational contexts: (a) achievement emotions are reactions to perceived success or failure (e.g. pride over a good grade or anxiety before an exam); (b) epistemic emotions are reactions to learning processes (e.g. enjoyment of gaining an insight or frustration when experiencing cognitive conflict); (c) social emotions are reactions to social interaction (e.g. developing friendships or conflicts in group work) and; (d) topic emotions are reactions to educational content (e.g. fascination for chemical processes or hopelessness regarding climate change).

In the sustainability education literature, much focus has been on (d) topic emotions, especially hope, worry, and anxiety related to climate change (Ojala 2023; Ojala et al. 2021; Pihkala 2022). Engineering education research has more often focused on (a) achievement emotions and (c) social emotions, particularly regarding students' ability to deal with exam anxiety and emotions in group work (e.g. Lehman et al. 2021; Rizwan et al. 2019; Román-Villanueva et al. 2019), as well as the role of empathy and compassion in design education and engineering ethics (e.g. Bairaktarova and Plumlee 2022; Kotluk and Tormey 2023); for an overview over the field, see Lönngren et al. (2023). More recently, engineering education researchers have begun exploring (b) epistemic emotions, especially focusing on students' emotional challenges as they engage with open-ended, ill-structured, and wicked problems (Lönngren, Adawi, and Svanström 2019; Swenson et al. 2021).

Social interaction theories explore emotions as social phenomena, paying attention to how emotions are co-constructed in and through interaction (Pepin 2008) – rather than approaching emotions as internal, psychological phenomena that are experienced by individuals. According to these theories, emotions are viewed as performed through verbal and non-verbal expressions, and those performances can influence how people interact and relate to each other (e.g. Edwards 1999; Wetherell 2013). Rather than as mental constructs, emotions are seen as complex '*intersections of language, desire, power, bodies, social structures, subjectivity, materiality and trauma*' (Zembylas 2016, 546). From this perspective, emotions are conceptualised as omnipresent – people cannot avoid expressing emotions and relating to the emotional expressions of others.

Engineering education researchers have recently begun exploring emotions and related constructs through social interaction approaches. For example, Silfver et al. (2022) have used discursive psychology to analyse female engineering students' gender(ed) discourses, finding that the students in their study presented themselves as not overly sensitive or caring to pass as 'authentic' engineers in male-dominated university degrees. Similarly, Cooper, Downing, and Brownell (2018) used discursive psychology to analyse designers' accounts of decision-making as including elements of emotion and intuition. More directly related to the present study, Lönngren, Adawi, and Berge (2021) used positioning theory and the concept of emotional positioning to study how engineering students relate to emotion norms when they discuss a wicked sustainability problem, finding that engineering students position engineering as purely rational, purely empathetic (i.e. requiring emotions), or both.

2.2. Expansive social learning in and for wicked sustainability challenges

Learning for, in and with wicked sustainability challenges involves developing capabilities to navigate complex, uncertain and ambiguous situations, oriented towards navigating and achieving systemic change (Larsson and Holmberg 2018; Lönngren 2017; Wals 2009). The kind of learning processes that capture the generation of such capabilities are commonly viewed as social, transformative and expansive (Lotz-Sisitka et al. 2015; Macintyre et al. 2018).

As mentioned in the introduction, in this paper we focus on social expansive learning, considered a distinct type of learning within the transformative learning paradigm (Hoggan 2016). It centres around the navigation and resolution of issues related to contradiction, dilemma and paradox through the formation of collective agency, new concepts and objects of activity (Engeström and Sannino 2010). In such learning processes, learners confront, react to and try to grapple with

wicked and problematic situations. This initial struggle gives way to a deepened analysis where structural constraints or contradictions may be surfaced and eventually overcome by the learners through the introduction of an innovative or broadened solution in context. While expansive learning processes may expose learners to moments of hopelessness, vulnerability, and uncertainty towards the unknown, they also hold potential for learning and change via open-ended processes of collective deliberation, negotiation, exploration and search. Metaphorically, expansion is about 'learning that is not yet there' (Engeström 2016). One concrete sign that such learning is occurring is when learners take increasing control over the direction and pace of their learning journey, effectively leading it themselves and moving beyond the instructions of the task at hand.

Expansive learning with wicked problems is cognitively and emotionally challenging for many engineering students. In an intervention study, Lönngren, Adawi, and Svanström (2019) found that students struggled as they were asked to deal with uncertainty and ambiguity, understand and reconcile stakeholders' perspectives and values, and approach the problem in a context-sensitive manner. They also found that it was not possible to help students overcome these challenges through cognitive scaffolding (e.g. detailed instructions on which issues they should discuss in addressing the problem) alone. Lönngren, Adawi, and Svanström (2019) concluded that learning to address wicked problems requires cognitive as well as emotional scaffolding.

2.3. Emotional scaffolding and scaffolding systems

Based on Vygotsky's work on sociocultural theories of learning, educational scaffolding has traditionally been conceived of as cognitive, meta-cognitive or affective/emotional interventions through which experts or more knowledgeable peers facilitate learning and forward movement through zones of proximal development (Rosiek 2003; van de Pol, Volman, and Beishuizen 2010; Wood, Bruner, and Ross 1976). While cognitive and meta-cognitive scaffolding has been researched extensively for a long time (van de Pol, Volman, and Beishuizen 2010), emotional scaffolding has received much less attention.

Lönngren, Adawi, and Holmén (2021) have defined *emotional scaffolding* as '*teachers' and peers' use of pedagogical tools that influence students' emotional experiences, expressions, and/or relationships in a way that promotes intended learning*' (2). Previous research has shown that emotional scaffolding is particularly important for expansive learning because it can be difficult for engineering students to achieve expansive learning with wicked problems if only cognitive and meta-cognitive scaffolding are provided (Lönngren, Adawi, and Svanström 2019).

Previous research on emotional scaffolding has focused on identifying generic strategies teachers can use to emotionally support students in difficult learning situations. In other words, emotional scaffolding has been conceived of as isolated interventions to be applied when needed. In this paper, however, we nuance Lönngren, Adawi, and Holmén's (2021) definition of emotional scaffolding as part of a more complex scaffolding system (Puntambekar 2022). The notion of scaffolding systems deepens and extends previous work on scaffolding by putting more emphasis on the distributed and systemic nature of teaching and social learning situations and the ways in which the effects of scaffolding interventions are contingent on a wide range of aspects including context. A systemic approach towards scaffolding is argued particularly important in research on sustainability education aiming to develop students' capabilities to handle wicked issues in open-ended processes or learning and change (Budwig 2015; Jordan 2016; Lönngren 2017).

3. Method(s)

3.1. Empirical contexts and data collection

In this study, we focus on students' emotional challenges and opportunities when dealing with wicked sustainability issues and the possibilities for emotional scaffolding to facilitate expansive learning in such situations and processes.

Acknowledging that emotions are an integral part of all social interaction and that all social interaction involves some form of learning, we conceive of emotional scaffolding as an omnipresent dimension of social interaction rather than a tool to be used in specific situations and for specific purposes. In other words, we refrain from essentialising emotional scaffolding and instead use it as an analytical lens to guide our attention to students' emotional interactions and the ways in which those interactions may hinder or enable expansive learning in complex scaffolding systems.

To explore emotional scaffolding for expansive social learning in regular teaching practice, we chose two existing master level courses at two Swedish universities in which engineering students engaged with wicked sustainability issues. Course A was a project-based course in which students worked in groups of six. At the beginning of the course, each group (with guidance) chose and framed a complex sustainability challenge they wanted to work with throughout the rest of the course. The groups that participated in our study focused on recycling of electronic waste (Group A1) and providing healthy snacks on campus (Group A2). In course B, students worked on several smaller group projects. For this study, we focused on a project in which students worked in groups of three (Group B1) to four (Group B2) on the controversial issue of maintaining a stable wolf population in Sweden. The overarching task for these students was to devise and administer a survey about people's attitudes towards wolves.

In total, 19 students participated in our study. For all groups, we video-recorded three separate group meetings, each lasting between 30 and 160 minutes. For each group, we rigged two video cameras to capture the scenes from different angles and a separate audio recording device to ensure good sound quality. Most of the meetings were held on site, and the groups worked independently on their projects. From time to time, course teachers joined to check in on the groups, answer questions, and/or provide feedback. During one meeting each, Groups B1 and B2 presented their project results to a course teacher, rather than working on their projects. These meetings were held and recorded via Zoom, with the second author present as an observer. In total, the empirical material comprises about 24 hours of video data. Ethical approval for the study has been granted by the Swedish Ethical Review Authority and we obtained written informed consent from all participating students and teachers.

3.2. Data analysis

Our analysis process was highly iterative and proceeded through five stages, including excerpt selection (Stage 1), separate analysis for each excerpt (Stages 2–3), and analysis across excerpts (Stages 4–5).

3.2.1 Stage 1: familiarisation and excerpt selection

To familiarise ourselves with the data, all authors watched all recordings at least once and each recording was watched multiple times by at least one author. Thereafter, we discussed our impressions in relation to previous research on emotions in environmental and sustainability education and our own research and teaching experiences. Based on those discussions, we formulated five (clusters of) sensitising concepts that guided our data selection to identify possible interesting situations on emotion and expansion: (a) closure – where students collectively converge around a certain choice, e.g. through consensus (b) opening – where students collectively diverge around different possibilities, e.g. through dissensus (c) intensity – when the standard rhythm and flow of the group work either intensifies or slows down, i.e. deviates from their normal dynamic, (d) enacted comfort or vulnerability and (e) social positions.

We selected a total of 18 excerpts from ten different group meetings in which our sensitising concepts appeared particularly relevant for understanding the roles of emotions and emotional scaffolding in social interaction and enacted learning. Five excerpts were from groups A1, A2, and B2 respectively, and three excerpts from group B1 (which interacted sparingly and mostly worked in silence on their laptops in a shared document).

3.2.2 Stage 2: piloting different analysis approaches

This stage consisted of two steps. The first step focused on unpacking each excerpt in its rich empirical nature by (i) in narrative form describing what happened in each excerpt, (ii) identify and describe observed emotional hindrances and enablers at play in the interaction and (iii) reflect on how the identified hindrances and enablers could have been reduced/leveraged through emotional scaffolding. Grounded in social interaction theories of emotion (Lönngren and Berge 2024; van Kleef 2016), we focused primarily on which emotions were expressed and how. We also aspired to identify emotional *absences* – that is, emotions that were *not* expressed – in contrast to culturally situated assumptions in our context about which emotions are typically expressed in sustainability courses for engineering students in Swedish higher education (mixed-gender groups of predominantly white and middle-income students and teachers).

The second step in this stage of the analysis explored the interplay between emotions, emotion objects and student learning in each excerpt through sketching systems maps, highlighting relationships and feedback between events, objects and emotions in each learning situation. Not all sensitising concepts were relevant for each excerpt, and each systems map therefore only involved one or a few of these concepts.

Through an iterative process of reflecting on and refining these systems maps, we were able to translate the generally abstract sensitising concepts into seven more concrete *analytic* concepts, each representing an object of emotion that stood out in the data we analysed:

- lack of time/resources
- lack of knowledge
- context-dependence
- uncertainty/unknowability
- value conflicts/ambiguity
- risk of failure/losing face (possibilities for success)
- limits of rationality

For example, one of our sensitising concepts was intensity. Through the analysis in Stage 2 we were able to identify more particular educational challenges students dealt with that could have led to a higher level of intensity in the interaction. From these challenges we were able to formulate analytic concepts. To ensure the relevance of our analytic concepts, we also compared them to challenges described in the literature on engineering education with wicked issues and open-ended design challenges (see section 2).

3.2.3 Stage 3: mapping enacted emotions for each excerpt

In this stage, we first mapped the emotions students enacted in each of the 18 excerpts, and the objects towards which those emotions were directed (for examples, see Figures 2–5). Emotions were enacted by one or several students and towards a variety of objects of emotions, including communication acts, educational challenges (the analytic concepts described above), the task, artefacts, and other students' enacted emotions. To categorise the enacted emotions, we considered semantics, prosody, facial expressions, gestures, body positions, gaze, and interaction with physical artefacts.

In line with our theoretical understanding of emotions as interaction, we did not attempt to identify which emotions individual students *experienced*. Our focus was only on which emotions students *enacted* and how. In this analysis, we relied on our culturally situated interpretations of (a) students' verbal and non-verbal communication acts, and (b) other students' reactions to those communication acts (e.g. if a student reacted by apologising, their apology could contribute to constructing a previously enacted emotion as angry or sad). As mentioned above, another important assumption in our analysis was that people always enact emotions, even if they neither move nor speak (which

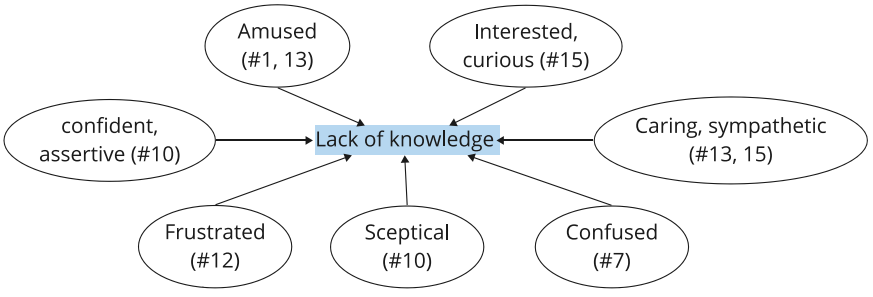

Figure 1. Example of an emotion map produced in Stage 4 of the analysis. Numbers in parentheses indicate in which excerpt an emotion (or a cluster of similar emotions) was observed.

could, for example, function to enact boredom or calmness). Each emotion map was developed by one author and thereafter discussed with the other author.

Next, we developed rich descriptions for each systems map, detailing which emotions were enacted by whom, towards which objects, and how. Triangulating between the systems maps, the rich descriptions, and the original data (video excerpts) we then documented our key insights about the relationships between emotions and emotion objects, as well as signs of emotional scaffolding in each excerpt. We discussed ways in which further emotional scaffolding could have facilitated deeper engagement with the educational challenges and, thereby, possibly enhance the expansive learning journey in each analysed situation.

3.2.4 Stage 4: mapping enacted emotions across excerpts for each analytic concept

To integrate our findings across excerpts, we developed a new set of illustrations depicting all emotions that were enacted towards each of our analytic concepts (for an example, see Figure 1).

3.2.5 Stage 5: mapping signs and possibilities of emotional scaffolding across excerpts and analytic concepts for expansive social learning

During this Stage, we sought evidence for and understanding of how emotional expressions may facilitate or hinder expansive social learning. Emotional scaffolding was used as an analytical lens to make sense of learning pathways in the student interactions, by highlighting how various scaffolding agents (individuals, groups) interacted across time and space to construct a distributed scaffolding system (Puntambekar 2022) within their social learning system in context (see Blackmore 2010).

First, we identified instances in our data where students moved towards or away from opportunities for expansive learning (i.e. engagement with the educational challenges represented by our analytic concepts). Thereafter we used the language of emotional scaffolding to make sense of how emotions enacted in those instances may have contributed to the observed movement towards/away from expansive learning. Acknowledging the systemic, social and situated nature of expansive learning and emotional scaffolding, we did not seek to derive any universal emotional scaffolding techniques that would guarantee expansive learning regardless of situation.

4. Results

Before presenting our results and responding to our research questions, we reiterate that we do not attempt to describe universal relationships between certain emotions and certain educational challenges. Instead, we have studied, and wish to highlight, the complex dynamics in which emotions emerge in student group work on wicked sustainability issues and how enacted emotions may influence learning for diverse engineering students with respect to context and learning situation. We end the result section with a reflection on how emotional scaffolding might be approached in

such open-ended and complex teaching and learning situations on wicked issues, which is then further extended in the discussion.

4.1. RQ1: relations between enacted emotions, objects of emotions, and possibilities for expansive learning

In the following subsection we present the situated enactment of emotions during students' group work, show the range of emotions enacted towards different objects of emotions, and provide reasoning into the observed relationships between emotions and learning in the analysed situations. To illustrate our results, we use four of the 18 excerpts we analysed for this study more in-depth. Table 1 provides an overview of those excerpts.

4.1.1 Situated enactment of emotions during student group work

To illustrate our findings on the situated enactment of emotions, we present the systems maps (Figures 2–5) for the four excepts described in Table 1. The systems maps depict students' enacted emotions (red text) towards specific interactions (text in black box) and educational challenges (highlighted text with different colours for different types of challenges). Arrows indicate temporal or causal relationships where solid lines indicate positive relationships and dashed lines negative relationships. Along the arrows, written text describes the nature of the relationship (e.g. 'increases') or the ways in which emotions are enacted through students' speech (e.g. 'It feels very difficult') or non-verbal communication (e.g. 'laughing'). To preserve students' anonymity, we refer to individual students as S1, S2, … , S19.

4.1.1.1 Excerpts 1 and 2: avoiding or embracing risk of failure. Excerpts 1 and 2 illustrate two different ways in which students dealt with combinations of low-controllability epistemic challenges (value conflicts/ambiguity and uncertainty/unknowability, respectively) with an achievement-related challenge (risk of failure/losing face). The students enacted emotions towards both types of challenges simultaneously, but the primary challenge in these excerpts appears to be risk of failure/losing face.

Excerpt 1 (Figure 2) is taken from a situation that occurred when Group B2 discussed some of the responses they had received on their survey. One of the questions in their survey asked respondents to indicate which political party they vote for. The group had designed the question for free-text answers, but they had not expected to receive answers that did not simply state the name of an established political party. However, one respondent had answered that they vote for '*whoever*

Table 1. Overview of four selected excerpts, outlining the activities students engaged in, educational challenges (emotion objects), primary enacted emotions, and learning processes/outcomes.

Excerpt, student group	Activities	Educational challenges (emotion objects)	Primary enacted emotions	Learning processes/ outcomes
1, B2	Discussing responses from a survey and starting to laugh	Risk of failure and losing face; values conflict and ambiguity	Amusement and contempt	Cohesion, us-them, ridiculing content and letting go of challenge
2, A1	Working on how to reduce electronic waste on campus	Risk of failure and losing face; uncertainty and unknowability;	Amusement and contempt	Relationality, courage, staying with the challenge, expansion
3, B1	Conversation into difficulty of economic valuation of environmental and social assets	Limits of rationality; risk of failure and losing face	Disengagement	Vulnerability, disconnection, moving on in silence
4, A1	Exploring reasons for why old electronics are not thrown away	Limits of rationality; risk of failure and losing face	Engagement	Excitement towards discovery and continuous exploration/expansion

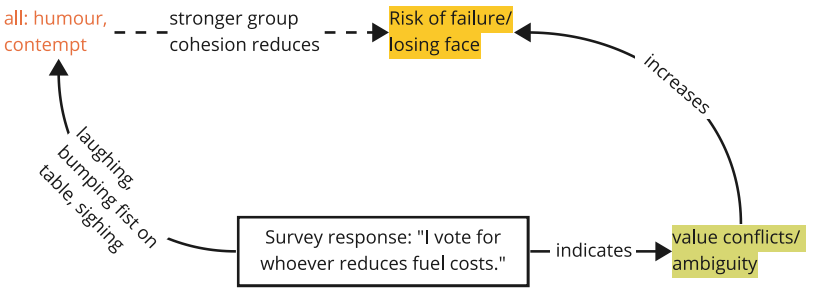

Figure 2. Schematic map of situated enactment of amusement and contempt in Excerpt 1.

reduces the (steadily increasing) fuel costs in Sweden'. The survey response confronted the students with ambiguity (e.g. regarding which party would reduce fuel costs the most, and which party the respondent might think would do that) and, potentially, values the students might not agree with. The presence of value conflicts/ambiguity, in turn, increased the risk of failing in the sense that there are several ways in which the students could deal with the survey response, none of which would be perfect. The students reacted to these challenges by ridiculing the survey response and, by extension, the respondent. Through laughing loudly, bumping a fist on the table, rocking back and forth with their upper bodies, and sighing, they collectively enacted strong emotions of amusement and contempt. The students' emotional enactment constructed the project group as a collective 'we', who is smarter than an anonymous outsider. Thus, the enactment strengthened group cohesion, which in turn could contribute to reducing the students perceived risk of failure for each individual student. Unfortunately, the collective enactment of contempt also hindered the students from constructively engage with the value conflicts/ambiguity they encountered in this situation. Thus, the enacted emotions may have limited the students' ability to take advantage of an opportunity for expansive social learning.

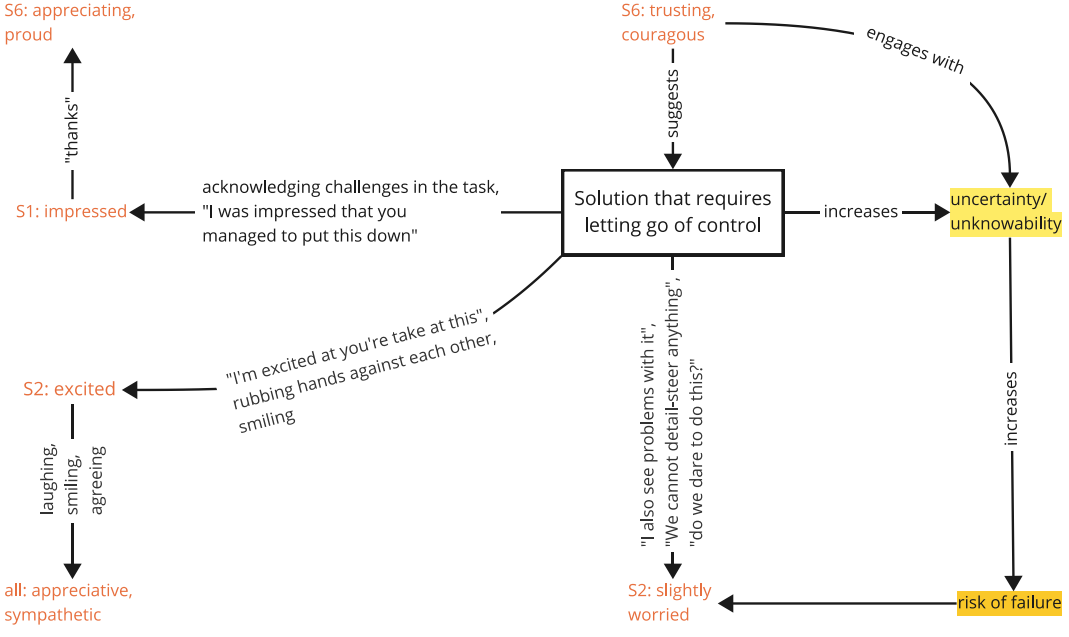

Figure 3. Schematic map of situated enactment of amusement and contempt in Excerpt 2.

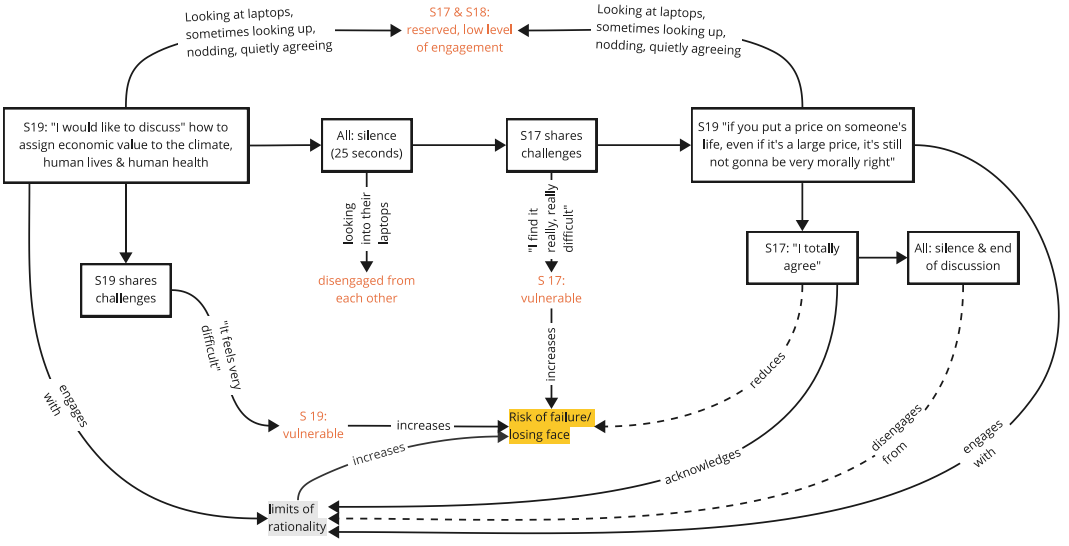

Figure 4. Schematic map of situated enactment of disengagement from limits of rationality in Excerpt 3.

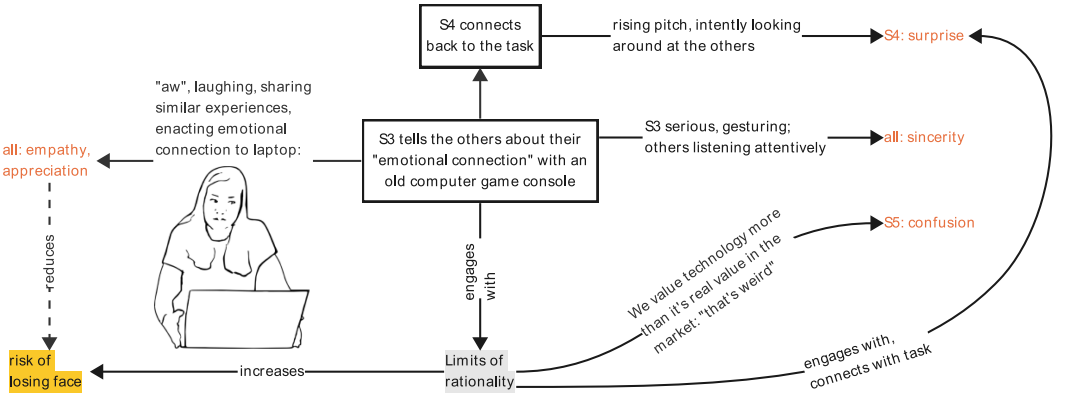

Figure 5. Schematic map of situated enactment of engagement with limits of rationality in Excerpt 4.

Excerpt 2 (Figure 3) is taken from one of the meetings of Group A1, when the students took turns to share their thoughts on how they could improve recycling of electronic waste on campus. One of the quieter group members (S6) suggested addressing the issue by strengthening students' relatedness towards the system of electronics production and recycling. In response to this suggestion, another student (S2) enacted strong excitement. S2 tried to interrupt S6, but S6 insisted on first finishing their report before giving the word to S2. S2 excused their interruption, saying '*I was just excited about your take on this*'. S2 enacted excitement through those words, but also by smiling at S6 and rubbing their palms against each other. The other group members corroborated and reproduced the enacted excitement by laughing, smiling, and agreeing verbally. Next, S2 enacted worry, stating they saw problems with the suggested approach since it would require letting go of a lot of control: '*we cannot detail-steer anything*' and must '*actually trust the process, to put the seed in the soil and then wait for it to happen*'. Through these utterances, S2 clearly acknowledges that the suggested solution increases uncertainty/unknowability, which in turn increases risk of failure. S2's utterances also retrospectively position S6 as courageous, since they dared suggesting a

solution that is both unconventional (at least for engineering students who are used to working with technical rather than social situations) and engages with uncertainty/unknowability. S1 further strengthened S6's position in the group, sharing own challenges and enacting admiration towards S6's achievement: '*I was trying to come up with the question with this [relatedness,] but I couldn't formulate it. It was so tricky. So I was impressed that you managed to put it down*'. S6 thanked S1, enacting pride and appreciation, saying '*good that I could provide something for the group*'. Overall, the students' enacted emotions in this situation made it possible for them to persevere in the face of uncertainty/unknowability and to engage in expansive social learning far beyond their regular technical curriculum.

Comparing the two situations described above, we noted that both groups were confronted with similar educational challenges: value conflicts/ambiguity (Excerpt 1) or uncertainty/unknowability (Excerpt 2), leading to an increased risk of failure/losing face. However, the groups dealt with those challenges in very different ways. Group B2 reduced the risk of failure/losing face by collectively enacting amusement and contempt towards an outside actor (the survey respondent). Thus, they avoided engaging with value conflicts/ambiguity. They also reduced their (perceived) risk of failing as they reframed a potential mistake on their behalf (allowing survey respondents to provide free-text answers) as someone else's (the respondent's) failure. Group A1, on the other hand, enacted excitement and admiration towards one of their group members: S6 had dared to expose themselves to the risk of failure by suggesting an unconventional solution that entailed a high degree of uncertainty/unknowability, and the other students praised S6 for their ability to formulate that suggestion. The group also enacted shared concerns about the risk of failure, but they dealt with those concerns by enacting shared courage, creating an opportunity for expansive learning for all group members.

4.1.1.2 Excerpts 3 and 4: managing failure in the face of limits of rationality. Excerpts 3 and 4 also contain risk of failure/losing face as an object of enacted emotions, but the primary challenge in these excerpts appears to be the limits of rationality, another epistemic object of emotion with low controllability.

Excerpt 3 (Figure 4) is taken from a situation in which Group B1 responded to a question in a written discussion guide provided by the teachers. The students took turns to share which topics they would like to discuss further. When it was S19's turn, they said: '*I would like to discuss how to value … [the climate crisis and the human lives and health], because it's, as we read in the text, was very very difficult to put dollars and cents on [those things]*'. In this statement, S19 talked about challenges in objectively determining economic value for assets that carry subjective value, and they constructed those challenges as worthy of discussion. Thus, S19 constructed an opportunity for the group to engage with limits of rationality and achieve expansive learning. S19 also exposed themselves to the risk of failure/losing face in front of the other students (S17 and S18), sharing that '*it feels very difficult*' to assign economic value to environmental and social assets. However, in contrast to the students in Excerpt 2, who enacted excitement and shared concern when S6 exposed themselves to risk of failure/losing face, S17 and S18 enacted low levels of engagement with S19's account: they mostly looked at their laptops, sometimes looking up at S19, nodding and/or agreeing in a low voice. When S19 finished, the whole group fell silent for 25 seconds, looking into their laptops. Thus, they enacted even stronger disengagement from each other.

While these emotional enactments of disengagement did not openly challenge S19, they also did little to reduce S19's risk of failure/losing face and to further engage with limits of rationality. First after the long silence, S17 validated S19's experiences, stating that S17 also '*[found] it really, really difficult*' and that '*it's really complex*'. Here, S17 enacted vulnerability and shared the risk of failure/losing face with S19, which could have opened another opportunity for collaboratively exploring limits of rationality. S19 responded sharing their opinion about economically valuating human life: '*If you put a price on someone's life, even if it's a large price, it's still not gonna be very morally right*'. Again, this statement could have triggered a discussion about limits of rationality, exploring

moral issues. However, S19 had stated their opinion (about limits of rationality) as if it was an objective and unquestionable truth: No matter how you deal with the challenge, you will be acting immorally. Spoken with falling intonation and looking down at their laptop, S19's statement left little room for dissent. This move hence reduced S19's risk of failing/losing face in front of S17 and 18, but it also hindered the group from further exploring limits of rationality. S17 responded '*I totally agree*', reducing their own risk of failure/losing face. After this statement, all students fell silent again.

Excerpt 4 (Figure 5) is taken from a situation in which students in Group A1 discussed possible drivers for insufficient recycling of electronic waste. In the context of that discussion, the students talked about old electronics which they, for diverse reasons, had not yet thrown away. S3 explained they hadn't been able to throw away an old video game console because '*[w]hen I was about to throw it out, I can't (sic), because I had an emotional connection with it*'. Acknowledging the importance of emotions in dealing with old electronics, S3 explicitly engaged with limits of rationality. At the same time, they increased their risk of losing face as they are breaking against dominant emotions norm in engineering, according to which **emotions** should not influence engineers (e.g. Lönngren, Adawi, and Holmén 2021). However, the group collectively enacted sincerity, validated the relevance of S3's account. S3 spoke in a serious tone, looking around at the other students, and the group listened attentively. At one point in the interaction, the other students also enacted strong emotions of empathy and appreciation, laughing together, exclaiming 'aw', and sharing similar experiences of feeling emotionally connected to electronic artefacts. S4 even reenacted an emotional connection to their own laptop, holding the device tightly between their flat hands. This reduced S3's risk of losing face, the group self-scaffolded caring relationships to further engage with limits of rationality.

Towards the end of Excerpt 4, S4 connected the group's experiences back to the task of identifying drivers for insufficient recycling of electronic waste: *'Do you think that it'll be a driver, like the emotional connection to your stuff?'* S4 used a rising pitch and intently looked around at the other students. Thereby, they enacted surprise about an unexpected insight (relevance of emotions for engineering) and invited the group to further explore this possibility. S5 confirmed that the insight was unexpected, enacting confusion: '*I think we definitely value this stuff [electronics] more than its real value in the market and … that's weird because … [it] should be kind of similar*'. The group continued to further explore the role of emotional connections for dealing with electronic waste, taking advantage of the opportunity for expansive learning.

As with Excerpts 1 and 2, Excerpts 3 and 4 describe situations in which students individually and collectively managed risks of failure/losing face. In Excerpt 3, they reduced the risk by enacting agreement, closure, and disengagement, which hindered further discussion of the issue S19 raised. Prematurely closing the discussion also hindered further engagement with limits of rationality and expansive learning. The students in Excerpt 4, in contrast, managed risks of failure/losing face by collectively enacting empathy, appreciation, sincerity, surprise, and confusion. Rather than closing the discussion, they further opened it as they shared personal experiences, enacted emotions (i.e. limits of rationality) related to the discussed topic, and actively connected emotions to the task they were working on. Thus, the group leveraged an opportunity to explore limits of rationality and engage in expansive learning.

4.1.2 The same enacted emotions can support and hinder expansive learning

As we tried to map enacted emotions to their objects and possibilities for expansive learning, we noted that the same type of emotional responses to an education challenge could facilitate *and* hinder expansive learning. For example, collective laughter could function to build positive group relations, ease tension, create excitement and lower the barriers to enter open-ended exploration into uncertainty whilst/by lowering the risk of failure.

In one excerpt, the students laughed as they faced uncertainty and openly expressed '*it is supposed to be like this, we are meant to fail, and we should trust the process / … / and hopefully the teacher will come and save us before we get too lost*'. Here, the students expressed some scepticism

but also curiosity, excitement and joy. The presumed presence of a teacher and the students' explicit intentions to engage in learning appear to have reduced risk of failure and created an emotionally safe and trusting space in which the students could explore uncertainty. In other excerpts, however, laughter appeared to primarily function to enact 'nice' group interactions in which everyone agreed with each other and where critical aspects or concerns – that could have been positive for expansive learning but potentially negative for the 'nice' atmosphere in the room – were not raised.

Hence, emotional scaffolding cannot be seen as isolated linear interventions targeted towards triggering the enactment of specific emotions that directly lead to a defined desired learning outcome. Instead, these findings reiterate the importance of appreciating the complexities of scaffolds and scaffolding systems.

4.1.3 Range of emotions enacted towards different objects of emotions

Based on all 18 excerpts, we identified that students in our study enacted a wide range of positive, negative, and neutral emotions towards the educational challenges included in our analysis. We noticed that some emotions (e.g. frustration, amusement) were expressed towards many of the challenges, while others (e.g. exasperation, pride) were expressed towards only a few (one or two). We also noticed patterns regarding which emotions were expressed towards which challenges and that many of the enacted emotions could be categorised as achievement emotions (e.g. related to fear of failing to complete the task) or epistemic emotions (e.g. related to ambiguity and uncertainty).

Below, we present the results in terms of which emotions were expressed towards epistemic versus achievement objects of emotions. This is a purely analytic and communicative separation: epistemic objects of emotions often appeared to be compounded with achievement objects of emotions. For example, students who enacted emotions towards the epistemic challenge of uncertainty/uncontrollability typically also enacted emotions towards the achievement-related challenge of risk of failure/losing face.

For epistemic objects of emotions, we noted that similar sets of emotions were enacted towards uncertainty/uncontrollability, value conflicts/ambiguity, and limits of rationality (Figure 6). These

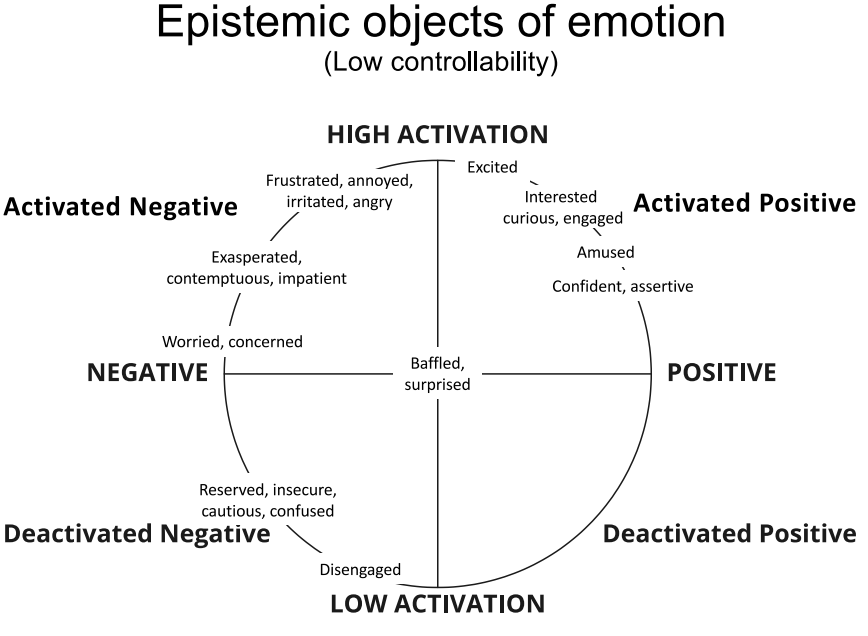

Figure 6. Emotions enacted towards epistemic challenges with low controllability (uncertainty, value conflicts/ambiguity and limits of rationality). Represented along the arousal-valence dimensions of the circumplex model of emotions (adapted from Barrett and Russell 1998).

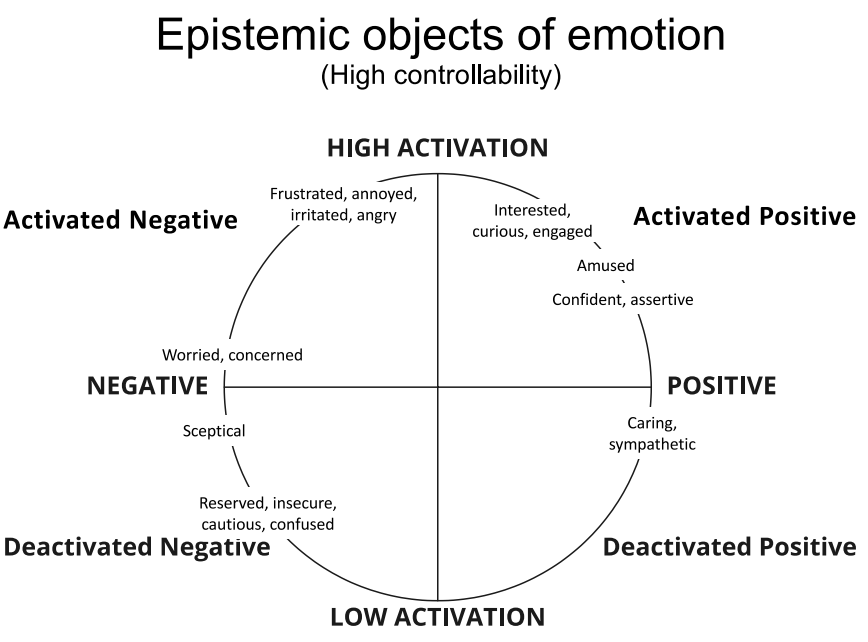

Figure 7. Emotions enacted towards lack of knowledge, an epistemic challenge with high controllability.

objects represent epistemic challenges that require students to deal with lack of control and predictability. Interestingly, we noted a different pattern of enacted emotions towards another epistemic challenge, the lack of knowledge (Figure 7). One reason for this difference may be that knowledge is more easily controlled since it often is possible to gather more information. Comparing the two patterns, we noted that epistemic objects of low controllability elicited a wider range of high activation emotions, both negative (exasperated, contemptuous, impatient) and positive (excited), than lack of knowledge, an epistemic object of high controllability.

Given the observation that students enacted different sets of emotions towards epistemic challenges of low versus high controllability, we could not see a clear pattern along this dimension alone. Therefore, we added a second dimension, the relative familiarity that most engineering students can be expected to have with the different types of challenges. For example, most engineering students are very familiar with lack of knowledge – which tends to be the reason they study in the first place – but they are often not used to dealing with the limits of rationality. As we applied these two dimensions – familiarity and control – to our data, a tentative pattern emerged in which educational challenges that were less controllable and less familiar tended to elicit more and stronger negative emotions (e.g. worry, frustration, irritation), while challenges that are highly controllable and familiar also elicited positive emotions (e.g. excitement, curiosity, confidence).

Positive epistemic emotions appeared to help students collectively tackle epistemic challenges, tensions, and dilemmas. For example, in one excerpt students expressed excitement and joy towards a task and the breadth of views, ideas and opinions that were voiced in the group. Low-activation positive epistemic emotions included curiosity and comfort, which appeared to support students in collectively dealing with lack of knowledge and the limits of rationality in several analysed excerpts.

For achievement emotions, we noticed that emotions enacted towards the educational challenge of risk of failure/losing face were closely related to emotions enacted towards an *education opportunity*: possibility of success. One reason for this relationship may be that there are no clear boundaries between good or bad solutions to wicked problems, which means that it is possible to fail and succeed at the same time, depending on, for example, how one frames the purpose of the learning situation and experiences the task. Another reason may be that both risk of failure and possibility of

success represent objects of achievement emotions. Thus, rather than trying to enforce an analytical separation between risk of failure/losing face and possibilities for success, we report the enacted emotions towards these two objects together (Figure 8). Taken together, these two objects elicited the greatest variety of enacted emotions among the students in our study, including positive, negative, high activation, and low activation emotions.

Finally, we noted that most situations in which emotions appeared to facilitate expansive learning involved students enacting positive, social emotions of relatively low activation, such as, students validating each other, listening, appreciating each other's ideas and suggestions. These enactments appeared to strengthen openness, social trust, and a sense of security and comfort in working together, which may have helped students deal with epistemic and achievement-related challenges. For example, in excerpts 3 and 4 (presented in the previous section), students expressed security and comfort, which may have lowered the risk of failure or reframed the risk as an opportunity for the group to learn. Thus, the students' performances of security and comfort could open possibilities for social expansive learning. Similarly, in other excerpts we could see how students' performances of vulnerability, care and trust facilitated their constructive engagement with complexity and uncertainty; students were able to experiment with new ideas and values, co-create new knowledge, practices and agency through more expansive modes of learning.

We also observed that students often were fiddling with pens, post-its or other material elements, especially when they encountered challenges. For example, in an excerpt where two students are debating, other students can be seen looking and playing around with a pencil or post-it note. We interpret these behaviours as a form of individual emotional self-scaffolding that may have helped students ease feelings of stress and unrest. This, in turn, may have allowed them to create space for others and to stay engaged in a challenging, exploratory and possibly expansive learning process.

4.2. RQ2: emotional scaffolding systems for social expansive learning

In this analysis emotional scaffolding functioned as an analytical lens to understand the types of emotional dynamics that may enable or hinder expansive learning. We viewed scaffolding as a

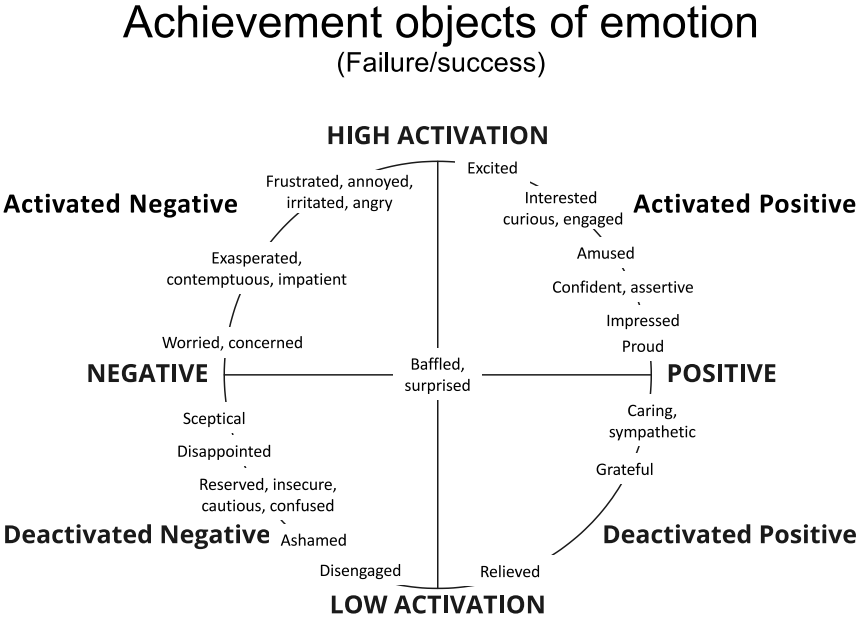

Figure 8. Emotions enacted towards achievement objects of emotion.

distributed system in which teachers can, but do not have to, play an important role in scaffolding learning in a certain direction. In the excerpts presented above, teachers were generally absent. This does however not mean they were not important for students' learning; they have been highly involved in shaping the emotional learning environments.

While they may have been physically absent in the situations, they were still available in the background and hold a formal responsibility for ensuring conditions for students to learn. Students could for example in some excerpts be heard referring to what teachers have said and done at previous sessions or in the whole class, illustrating temporally distributed scaffolding.

In other exceprts part of the analysis but not presented in detail above, real-time encounters with teachers appeared to directly unlock expansive potential, for example when teachers legitimised students' efforts in challenging, transgressing or re-framing the tasks at hand – which we get back to further below.

4.2.1 Interaction of social and material elements in emotional scaffolding systems

All situations studied contain interactions between social and material elements, encompassing emotional scaffolding systems embedded in their wider social learning system and context (see Blackmore 2010). Most often, such situations consist of social interactions, the task, material elements (such as post-its or computers), and emotions.

In Excerpt 2, students moved into uncertainty through emotional scaffolding in the form of group members enacting an emotional connection. Sitting around a table, the students were able to look each other in the eyes and perform active listening. The students enacted shared excitement about the issue they were working on, and they co-created an open atmosphere through validation, smiling, and appreciation, which reduced the risk of failure and making the open-ended exploration into uncertainty increasingly safe and attractive. The post-it notes contributed to the scaffolding system by providing a frame for how much each student was supposed to talk without interruption (students presented on post-it at a time, before putting it on a big sheet of paper). One student provided emotional scaffolding by metaphorically describing the situation as necessarily uncertain and emergent, stating that addressing their chosen issue required them to '*put a seed in the soil and wait for it to happen*'. The group also collectively reminded themselves that they must '*trust the process*'.

In another excerpt the emotional scaffolding system comprised, among other elements, a framework with pre-defined categories, post-it notes that the students used to brainstorm and clustered ideas, a teacher who first observed and then provided guidance on how to approach and make sense of the task, and students' laughter, engagement and openness to humour. Together, these elements enabled the students to take an expansive learning pathway, where they eventually decided to transgress pre-defined categories and put post-its 'in-between' categoires, thereby overcoming conflicting opinions in the group and a sense of being stuck. The teacher carefully scaffolded this expansion through reinforcing and justifying student voices and enhancing legitimacy for the group to eventually transgress the categories.

4.2.2 Exploring leverage points for emotional scaffolding

By approaching scaffolding as systemic (Puntambekar 2022) we now connect the concept of scaffolding systems with Donella Meadows' conceptualisation of leverage points as places of potential in a system where a smaller shift can produce bigger changes, ranging from shallow to deep (Abson et al. 2017; Meadows 1997). The combination of scaffolding systems with leverage point thinking provides a scheme that allows for classifying scaffolding strategies or intents as ranging from incremental (shallow) to transformative (deep), in terms of their contribution to processes of learning and so change. Shallow scaffolding typically translates into problems to be solved in the direct learning environment or situation, which to large extents are about buffering or regulating the amounts of certain emotions, whereas the deeper levels may require transformations of the emotional logic underpinning teaching and learning as well as exploration into new activities that go well beyond the initial framing or task at hand. Table 2 presents examples of emotional

Table 2. Emotional scaffolding intentions on different leverage levels.

Leverage level	Examples of scaffolding intentions
Shallow: Emotional tweaking	• Leverage enjoyment • Leverage engagement with topic/task/group
Medium: Emotional re-articulating	• Reassure • Lower perceived risk • Work through/reframe negative emotions • Leverage positive emotions • Clarify/normalise experience of challenges
Deep: Emotional re-framing	• Reframe risk/challenges to possibilities • Leverage positive imaginaries for the issue at hand/society/own identities as future engineers

Notes: The classification ranges from shallow adjustments to learning environments to deeper transformations of the emotional logic underpinning teaching and learning. The shallow is more about situations that require coping with certain tensions that influence learning, whereas the deep is more about overcoming tensions or use them strategically and intentionally for learning.

scaffolding intentions ranting from shallow to deep at three different leverage levels (shallow, medium, deep).

Relatively shallow and simple emotional scaffolding intentions may focus on creating enjoyment or engagement with a topic, task or group. Such scaffolding, which we call *emotional tweaking*, may accelerate expansive learning for groups that are already on such trajectories, but it may not necessarily be enough to shift learning into an expansive path in the first place.

Medium-level emotional scaffolding can consist of *emotional re-articulation*. In our data, such re-articulation included re-assuring and lowering the perceived risk of, for example, entering and navigating uncertain terrains to enable students to deviate from their path and embark upon an alternative learning journey. Other examples included supporting students in working through, regulating or reframing negative emotions, leveraging positive emotions, or clarifying and normalising the challenges and experiences students were expected to face when dealing with wicked sustainability issues.

Oftentimes, however, opening pathways for expansive learning may require deep emotional scaffolding or *emotional reframing*. At this level, emotional scaffolding in our data involved re-framing risks and challenges into possibilities or shifting the view from solving (negative) problems to leveraging positive imaginaries for the issue at hand. For example, failure can be re-framed as possibilities for learning and transformation. Therefore, emotional scaffolding for such re-framing could focus on enacting excitement or curiosity towards educational challenges. This form of scaffolding could also contribute to broadening engineering practice beyond purely instrumental approaches that are designed to minimise emotionality and uncertainty – at the expense of expansion and transformation.

Coping with limits of rationality and moving beyond a rational framing of engineering problems can be uncomfortable and even considered inappropriate in many contexts. However, given the constant presence of open-ended complexity, uncertainty, ambiguity and conflicting norms and values when dealing with wicked sustainability issues (Leach, Scoones, and Stirling 2010; Lönngren and van Poeck 2021; Ross and Mitchell 2018), engaging with emotions and the unknown is from the view of this study considered key to adequately and responsibly cope with such situations.

5. Discussion

In this study, we explored interactions between emotions, object of enacted emotions and possibilities for expansive learning in engineering students' work with wicked sustainability issues. We then analysed the roles of and possibilities for emotional scaffolding to influence and enhance learning in such work. Emotional scaffolding systems were used as analytical lens and connected with leverage point thinking to provide a classification of scaffolding intents and strategies ranging from shallow to deep, to expand learning in (engineering) education for sustainability.

5.1. Emotional scaffolding for social expansive learning

Our theoretical choices allowed us to explore emotional scaffolding as a complex, systemic and situated phenomenon (Puntambekar 2022). Within the framework of our study, emotions were not viewed as isolated internal experiences on an individual level but recognised as situated and produced via social interactions within a learning community or system (Blackmore 2010; Wenger 1998). We found that emotional scaffolding for expansive learning is less about controlling students' learning through isolated, linear and teacher-led interventions and more about introducing or tuning certain elements and mechanisms within a social-material learning system in context. Emotional scaffolding in line with social expansive learning involves the building and nurturing of an emotionally safe learning environment where students and teachers enact trust, vulnerability, openness and care. This finding is in line with educational traditions such as relational (Bovill 2020) or brave/safe space pedagogy (e.g. Arao and Clemens 2013) and pedagogies of hope (hooks 2003).

Expansive learning involves confronting and working through problematic situations, tensions or dilemmas, rather than avoiding them (Engeström 2016). Groups that fostered participation, built positive relationships, and trusted the learning and exploration process were more open to addressing these challenges constructively. Humour and shared laughter were identified as helpful to reduce social barriers and enhance group cohesion, but occasionaly also shifted focus away from the problematic situation at hand resulting in pleasant social interaction.

Purposeful and deliberate emotional scaffolding for expansive learning benefit from contextual sensibility. This study presents empirical evidence showing that similar emotions can lead to different learning processes and outcomes, depending on specific social interactions and contextual factors. This complexity does not render emotional scaffolding impractical; rather, it highlights its nuanced and non-instrumental application, grounded in care, where teachers, students and other actors collaboratively shape a positive emotional learning environment.

Interesting learning dynamics arise when student groups working on wicked sustainability issues find themselves at crossroads: e.g. delving deeper into analysing the problem, exploring alternative solution pathways, or generating particular (conceptual) solutions. Progress in an expansive learning process may involve not only 'moving forward' in a traditional problem-solving sense but also reframing objectives or redefining the task or activity itself (Engeström 2016). Our findings illustrate the intricate interplay between moving deep, moving broad, and moving forward in complex learning situations related to sustainability issues (McCrory et al. 2021; Pohl et al. 2020). Furthermore, our study emphasises the importance of (emotional) scaffolding in all these directions to support expansive learning, recognising that desired learning trajectories may be plural and contingent on the specific situation and problem at hand. Building on Puntambekar's (2022) work on scaffolding systems, our findings provide further empirical support towards viewing zones of proximal development in expansive learning for sustainability not as mono-progressions along a pre-determined path, but as multi-dimensional spaces of possibility extending toward the boundaries of the unknown (Cf. Engeström 2016).

As expansive learning processes are, by definition, open-ended – with outcomes emerging through the process rather than being pre-defined – scaffolding such learning should focus on creating space and conditions for learning rather than steering or controlling it toward predetermined goals. In this study, we conceptualised learning as occurring within social and open systems (Blackmore 2010), where scaffolding involves tuning or shifting internal dynamics from within rather than manipulating systems from the outset (Cf. Maturana and Varela 1980). Budwig (2013; 2015) describes scaffolding in such contexts as an art of guided emergence, emphasising the complexity of supporting open-ended learning processes. Moving away from the interventionist logic of scaffolding, particularly with respect to the connections drawn between scaffolding systems and leverage points in this study, we build on McCrory (2022) and Cheney and Weston (1999), and propose that teachers and scholars continue to work towards conceptions of emotional scaffolding for expansive learning

as deliberate *invitations* rather than controlled *interventions*. With this statement, we transition to the next subsection, which outlines areas for further research.

5.2. Future research

Previous research on emotions in education has focused on achievement emotions, for example exploring exam anxiety and ways to help reduce it (Pekrun and Linnenbrink-Garcia 2014). Research on emotions in sustainability education, on the other hand, has primarily focused on topic emotions, such as hope and anxiety in the face of climate change (Grund, Singer-Brodowski, and Büssing 2024). Epistemic emotions have also received some attention, not least in engineering education research (Swenson, Treadway, and Beranger 2024). However, as far as we know, little research has explored how different types of emotions can relate to each other in open-ended learning processes. In our study, we found that epistemic and achievement emotions often appeared together. We suspect that emotional scaffolding directed towards only one of them may be counterproductive. For example, scaffolding for dealing with achievement emotions may be ineffective if achievement emotions are triggered by epistemic challenges. At the same time, scaffolding for dealing with prospective outcome and achievement emotions may reduce the risk of failure and the fear of losing face, which in turn can help students deal with epistemic emotions. Empirical studies into the interaction of different types of emotions and their relation to desired learning processes and outcomes represent a fruitful avenue for further research.

We can also start to compare collaborative or distributed emotional scaffolding with group level emotion regulation (Järvenoja, Näykki, and Törmänen 2019). Based on analysis of students engaging in collaborative learning during a mathematics course, Järvenoja et al. concluded that '*co- and socially shared emotional regulation during collaborative learning is relatively rare*' (1754). Our study indicates the opposite: emotional scaffolding, just like emotions, seems to always be present in one form or another, albeit to varying degrees. Exploring systems of distributed emotional scaffolding allowed us to explore our participants' enacted emotions – and their relations to opportunities for expansive learning – with a much greater breadth and resolution than what has so far been achieved in research on co- and socially shared emotion regulation. Previous research has been largely informed by research on individual emotion regulation, which Järvenoja et al. acknowledge as an important limitation since '*collaborative learning situations can generate regulation mechanisms inherent for its [collaborative] nature*' (1754).

In addition, analysing scaffolding in situated learning via social and material scaffolds, as parts of scaffolding systems (Puntambekar 2022), rather than merely from teacher-led interventions, provided important methodological and theoretical advantages. For example, we could analyse a wider range of situations that were pivotal for expansive learning because we did not need to limit ourselves to studying learning situations where teachers where in charge of performing scaffolding interventions.

The approach to emotions and scaffolding systems in this study allowed for analysing how emotional scaffolding functioned to activate, validate or regulate certain emotions via the use of language, material artefacts or other types of tools and signs. The approach also allowed for recognising that emotions themselves become scaffolds that support certain emotions, in giving shape of a (positive) emotional learning environment. However, this study has only begun to explore the complexities of emotional scaffolding and the role of emotions within scaffolding systems. Further research is needed to deepen our understanding of these phenomena and to enhance conceptual clarity. Especially, more theoretical and empirical work is required to analyse the relationships between interaction theories of emotion.

Additionally, further theoretical and empirical work is needed to analyse the relationships between interaction theories of emotions (e.g. van Kleef 2016), social learning systems (Blackmore 2010), scaffolding systems (Puntambekar 2022) and leverage points (Meadows 1997). Beyond providing conceptual contributions through careful exploration into the functioning and foundations

of these theories and their possible (in)commensurabilities, such efforts could pave the way for new theoretical advancements and support in generating more grounded research approaches specifically designed to study emotions in social learning contexts. This, in turn, would enhance methodological rigour in research on emotions in engineering education (Cf. Lönngren et al. 2024), and in particular with respect to wicked sustainability issues.

Finally, emotional scaffolding has a theoretical resemblance with other theories of emotional support for learning processes that tend to elicit strong epistemic emotions among engineering students, such as open-ended problems, uncertainty, or value conflicts. Most notably, Swenson, Treadway, and Beranger (2024) have approached emotional support for individual students through the lens of productive epistemic meta-affect. They define epistemic meta-affect as the self-directed capacity to recognise, articulate, reframe, and regulate emotions in complex problem-solving. Epistemic meta-affect may be particularly useful for supporting engineering students in identifying, managing and contextualising emotions in ways that challenge and transform deeply held beliefs about what it means to learn and become engineers in the twenty-first century (see Hadgraft and Kolmos 2020; Holmén, Adawi, and Holmberg 2021; Jamison, Kolmos, and Holgaard 2014 for some work widening what engineers are and could be). Future research could explore how meta-affect can be studied from social interactionist perspectives, such as those used in this study. We also request research shedding light on conceptual and empirical relationships between, for example, emotional scaffolding, productive epistemic meta-affect, and co- and socially shared emotional regulation (Järvenoja, Näykki, and Törmänen 2019).

5.3. Implication for practice

This study highlights the critical role of emotions in learning about/for/in wicked sustainability issues and offer practical strategies to address common challenges in educational settings dealing with such. To support expansive learning in such learning processes, three challenges that are particularly common and associated scaffolding strategies can be highlighted from this study: (i) reframe failure as learning by e.g. lowering or re-framing the perceived risk of failing in a spirit of learning and care; (ii) normalise tensions and contradictions by e.g. helping students see dilemmas and value clashes as natural and necessary for progress on wicked sustainability issues, and; (iii) foster comfort with uncertainty by e.g. encouraging groups to embrace exploration and remain open to not knowing.

In more detail, we identified two dimensions of variation that in practice can help understand the diversity of emotions students may enact towards different educational challenges while working on wicked sustainability issues: *controllability* and *familiarity*. Both dimensions are closely related to the level of difficulty that a challenge can be expected to pose for students and – consequently – the types and amounts of emotional scaffolding needed to support students in overcoming that type of challenge and facilitating social expansive learning. An illustration of these dimensions with respect to various learning challenges is now presented in further detail below and summarised in Figure 9.

For challenges with high controllability and familiarity (e.g. lack of knowledge, lack of time), it may be relatively easy for educators to provide students with tools and instructions that guide them to monitor their emotional responses and self-scaffold for expansive learning. When students encounter a situation where they lack knowledge to move on, a *possibility for learning* may be opened as it invites for simply searching new information or perhaps more challenging creating new knowledge. A situation characterised by shortage of time may not only be perceived as negative or stressful, but also a *nudge to move on*. When encountering context-dependencies and contingency statements, students may start to familiarise themselves with their particular context, providing choice and a *possibility for concretisation*. Uncertainties, unknowns and risks of failure do not necessarily have to be perceived as scary or threatening situations but may also be framed as situations holding excitement and more importantly for expansive learning, *unknown possibilities*.

The more and most difficult challenges, characterised by lower controllability and familiarity (e.g. limits of rationality, value conflicts/ambiguity) may need repeated scaffolding and explicit training to

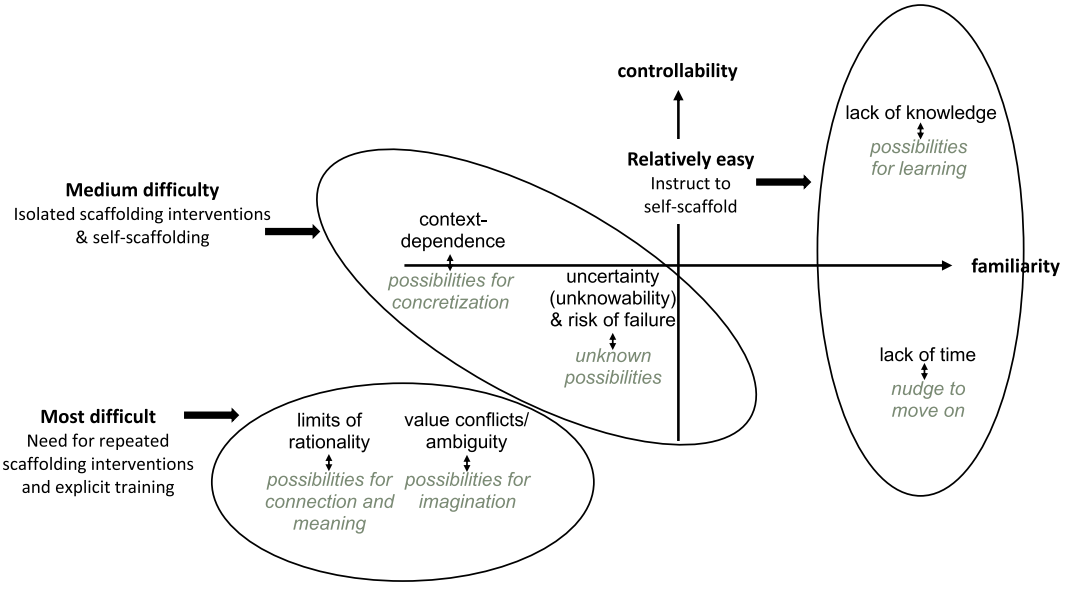

Figure 9. Deep level emotional scaffolding, posing possible expansive learning shifts in relation to each analytical concept. Apart from lack of time, the excerpts we analysed were largely dominated by epistemic emotions.

create opportunities for expansive learning. Finally, limits of rationality provide a possibility to connect and make meaning in terms of what it means to be human, and value conflicts/ambiguity may not only create anxiety but also for imagining things differently.

A sensitivity to educational challenges, with attention to controllability and familiarity, combined with the classification of scaffolding intents from shallow to deep (Table 2), offers practical guidance for students and educators in shaping learning environments that support transformative social learning for sustainability in general and expansive learning in particular. N.b. that expansive learning does not necessarily require deep scaffolding to occur. Groups may naturally embark on an expansive learning journey, meaning that shallow scaffolding may be sufficient to sustain and enhance their progress along this path.

6. Conclusion

In this study, we focused on the emotional challenges and opportunities in engineering students' learning about, with and for wicked sustainability issues. While cognitive challenges have been studied extensively in engineering education research, emotional aspects of complex problem solving and engineering learning are often overlooked (Lönngren, Adawi, and Holmén 2021). We explored how *emotional scaffolding* can support engineering students in co-creating *new* ways of handling wicked issues via expansive learning. Our analysis identified seven types of educational challenges that appeared to trigger expression of a wide range of emotions. We nuanced previous research showing that emotions play a critical role in transformative sustainability learning, illustrating diverse ways in which engineering students enacted emotions towards educational challenges, and how they could perform collaborative, distributed emotional scaffolding to overcome those challenges to create opportunities for expansive learning.

The study has contributed to research on scaffolding, emotions, expansive learning, and collaborative learning in engineering education by (1) providing empirical examples of how scaffolding systems (Puntambekar 2022), with interacting social and material elements, can support collaborative learning in engineering education, (2) demonstrating how student groups can shape their own

expansive learning pathways by constructing and leveraging emotional scaffolding systems to overcome educational challenges, and (3) illustrating how research on emotional scaffolding can become more analytically precise, by combining it with the academic emotions framework (Pekrun and Linnenbrink-Garcia 2012), to study diverse ways in which emotional scaffolding can target achievement, topic, social and epistemic emotions.

Acknowledging the presence and importance of emotions in transformative sustainability learning calls for an 'inwards-turn' in (engineering) education for sustainability, that extends beyond mindfulness or meditation practices (Cf. Libertson 2023; Wamsler 2020). Emotional scaffolding for expansive learning, as conceptualised in this study, seeks to support students and student groups in surfacing, critically examining and revising worldviews, beliefs, assumptions, boundaries, identities and values in practical engagement with wicked sustainability issues – not only reproducing problematic systems and structures but also purposefully transforming them on a level of individual, group and wider society. We here forwarded a classification of emotional scaffolding intents for expansive learning, ranging from shallow to deep (emotional tweaking, re-articulating and re-framing) – from shallow adjustments to learning environments to deeper transformations of the emotional logic underpinning teaching and learning.

Finally, engineering educators may be tempted to design learning situations that promote 'appropriate' emotional responses, focusing on emotional intelligence, regulation, and management in classrooms (Lönngren et al. 2024). However, our findings reinforce that emotions are complex social phenomena that cannot be engineered or controlled. Expansive social learning in societal transformations imply open-ended exploration and knowledge creation under conditions of uncertainty and ambiguity. Here, educators can play an important role in creating conditions where students become aware of, reflect upon, and collaboratively navigate emotional experiences. Acknowledging the importance and complexity of emotions in expansive social learning empowers educators and students to co-create increasingly challenge-centred and transformational learning environments, ultimately enhancing students' capabilities to meaningfully engage with wicked sustainability issues.

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